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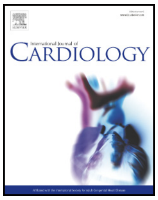

Combined associations of sedentary behavior and cardiorespiratory fitness on cognitive function among older adults

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ABSTRACT

Background: Sedentary behavior, cardiorespiratory fitness, cognition and age are interrelated and associated with cardiovascular function. No study, however, has specifically evaluated the independent and combined associations of cardiorespiratory fitness and sedentary behavior on cognition, which was this study's purpose.
Methods: Data from the 1999–2002 NHANES were used ($N = 2451$; 60–85 yrs). Sedentary behavior was assessed via self-report; cardiorespiratory fitness was assessed from a medical-related algorithm; and cognition function was assessed from the Digit Symbol Substitution Test (DSST).
Results: Being in the bottom quartile for sedentary behavior ($\beta = 2.13$; 95% CI: 0.49–3.77; $P = 0.01$) and the top quartile for cardiorespiratory fitness ($\beta = 7.48$; 95% CI: 5.4–9.5; $P < 0.001$) were independently associated with higher cognitive function. In the additive model, those with an index score of 1 (vs. 0) and 2 (vs. 0), respectively, had a 3.87 ($\beta = 3.87$; 95% CI: 1.76–5.98; $P = 0.001$) and 10.40 ($\beta = 10.4$; 95% CI: 7.31–13.5; $P < 0.001$) higher DSST score.
Conclusion: High cardiorespiratory fitness and low sedentary behavior were jointly associated with the highest cognitive function. This has important cardiovascular implications as a progression of neurocognitive impairment is associated with increasingly severe manifestations of cardiovascular disease.

1. Introduction

Progression of neurocognitive impairment is associated with increasingly severe manifestations of cardiovascular risk and disease [1]. Thus, identifying modifiable factors associated with both cardiovascular disease and cognition among older adults is of major medical and public health interest. Our previous work demonstrates that walking performance and duration of heart failure status may play an important role on cognitive function status [2]. Cognitive decline is considered to be a normal outcome of aging. Notably, some cognitive parameters, such as vocabulary, are considered to be relatively stable and do not attenuate much over time. Other parameters, often referred to as fluid intelligence, are more subject to change with age [3]. Examples of fluid intelligence include executive function (cognitive abilities that foster goal setting and motivation processes, including self-monitoring, planning, organizing, reasoning, problem-solving, and mental flexibility) [4], processing speed, memory, and psychomotor ability. Declines in these and other cognitive parameters may result in decreased functional abilities [5], which may negatively influence an individual's independence [6]. This is one pathway proposed to explain the association between cognitive declines and reduced quality of life [6].

Although genetics may, in part, explain differences in cognition, various behavioral factors have also been associated with cognitive function [4]. Considering the importance of not only extending the lifespan and improving quality of life among the older adult population, it is worthwhile to investigate the associations of modifiable risk factors with cognitive decline. Notably, this notion is endorsed by the CDC & the Alzheimer's Associations' *Healthy Brain Initiative* [7], which is dedicated to building a strong evidence base for programmatic interventions for improving cognitive health. Identifying factors associated with cognitive function can thus serve as a cornerstone in the formation of health promotion strategies designed to attenuate the cognitive declines that occur from aging.

Cardiorespiratory fitness and sedentary behavior are two factors that have been shown to associate with cognitive health [8]. For instance, previous longitudinal work has demonstrated associations between greater baseline cardiorespiratory fitness with a lower decline in cognitive function as well as lower cognitive task performance [8]. Notably, the previous example is only one among numerous studies,

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Table 1
Characteristics of the study variables, 1999–2002 NHANES ($N = 2451$).

Variable	Point estimate	95% CI
Age, mean years	69.8	69.4–70.4
Cognitive function, mean DSST	47.7	46.5–49.0
Sedentary behavior, mean h/day	2.7	2.6–2.8
Cardiorespiratory fitness, mean METS	7.7	7.6–7.9
MVPA MET-min-month, mean	3527.9	2918.8–4136.9
Gender		
% Female	55.1	
Race-ethnicity, %		
Mexican American	2.9	
Non-Hispanic White	83.7	
Non-Hispanic Black	6.7	
Other — including multiracial	6.7	
Coronary artery disease, %		
Yes	9.8	

DSST, Digit Symbol Substitution Test.
MET, Metabolic Equivalent of Task.
MVPA, Moderate-to-vigorous physical activity.

including experimental interventions, which constitute a breadth of existing research on this topic. The expansiveness of this work is illustrated through the numerous reviews that have been published on fitness and cognitive function [9–15]. While some previous meta-analytic reviews on aerobic fitness training intervention studies and cognition have concluded that fitness training has moderate-to-large benefits for cognitive health [9,10], others have suggested mixed or inconclusive evidence [11,12]. While convincing evidence of a positive association between cardiorespiratory fitness and cognitive health exists [8–10,13–15], more research is needed to better understand the underlying mechanisms that may mediate this relationship.

In comparison to cardiorespiratory fitness, sedentary behavior has been less investigated as a potential predictor of cognitive health. This is likely due to sedentary behavior only recently emerging as being independently associated with numerous health outcomes [16,17]. A 2016 systematic review by Falck et al. [18] was reportedly the first review of this nature to be conducted on sedentary behavior and cognitive function. This review provided substantial evidence, as demonstrated per observational studies, for an inverse relationship between sedentary behavior and cognition. Given that sedentary behavior research is still in its infancy [17], and much of the existing sedentary behavior work has evaluated cardiometabolic factors [16,19–21], future work exploring other health-related outcomes (e.g., cognitive function) is warranted [18].

Taken together, the previously mentioned findings regarding cardiorespiratory fitness and sedentary behavior associations with cognitive health set the stage for the present study. In extension of this previous work, the purpose of the present study was to evaluate both the independent and combined associations of these variables on cognitive function, which is uncommonly investigated in the literature. Notably, this approach enables the assessment of multiple concomitant risk factors, which may assist with more realistic health promotion strategies that take into account individuals who may have more than one present risk factor.

2. Methods

2.1. Design and participants

The 1999–2002 National Health and Nutrition Examination Survey (NHANES) data was used to analyze 2451 older adult (60–85 yrs) participants with data on the study variables. These cycles were selected as these are the only current NHANES cycles with cognitive function data. The NHANES is an ongoing survey conducted by the Center for Disease Control and Prevention designed to evaluate the health status of U.S. adults through a complex, multistage, stratified clustered probability design. The study was approved by the National Center for Health Statistics ethics committee. All participants provided written informed consent prior to data collection.

2.2. Cognitive function

The Digit Symbol Substitution Test (DSST) was used to assess cognitive function. The DSST, a component of the Wechsler Adult Intelligence Test [22] and a test of visuospatial and motor speed-of-processing, has a considerable executive function component and is frequently used as a sensitive measure of frontal lobe executive functions [23,24]. The DSST was used to assess participant cognitive function tasks of pairing (each digit 1–9 has a symbol it is associated with) and free recall (allowing participants to draw more figures in the limited time due to remembering pairs). Participants were asked to draw as many symbols as possible that were paired with numbers within 2 min. Following the standard scoring method, one point is given for each correctly drawn and matched symbol, and one point is subtracted for each incorrectly drawn and matched symbol, with a maximum score of 133.

2.3. Sedentary time

As described elsewhere [25], participants were asked, "*Over the past 30 days, on a typical day how much time altogether did you spend on a typical day sitting and watching TV or videos or using a computer outside of work?*" Response options were: <1 h, 1 h, 2 h, 3 h, 4 h, or 5 + h. This screen-based sedentary behavior item has demonstrated some evidence of convergent validity by correlating with body mass index categories [26]. Using data from the 2003–2006 NHANES (cycles with objective 'overall' sedentary data), we computed the correlation between this self-report screen-based sedentary behavior item and identical categories (h/day) of accelerometer-determined sedentary behavior (counts/min < 100); a weak statistically significant association ($r = 0.10$, $p < 0.0001$) was observed, which is not unexpected as this self-report screen-based sedentary item only assessed non-occupational sedentary behavior, whereas accelerometry assesses overall daily sedentary behavior. This observed correlation is within the range ($r = -0.19$ to 0.80) of a review paper documenting the concurrent validity of television viewing time and other non-occupational sedentary behaviors (referent measures included heart rate monitoring, behavioral logs and accelerometry combined with behavioral logs) [27]; notably, only 3 of the evaluated studies from this review examined the validity of self-reported television viewing time and other non-occupational sedentary behaviors. This review, did, however, demonstrate moderate-to-high reliability of these measures (the majority of the ICC's were >0.5).

2.4. Cardiorespiratory fitness

Cardiorespiratory fitness was estimated from a recently developed algorithm that was derived to estimate cardiorespiratory fitness [28]. The NHANES objectively-measured (via submaximal treadmill test) cardiorespiratory fitness data was not used herein because this treadmill-based test was only administered among individuals <50 years and did not occur in the 2005–2006 NHANES cycle, and notably, the cognitive function test was only administered among adults 65 + years. The equation for this utilized cardiorespiratory fitness algorithm is as follows:

Women

$$\begin{aligned}\text{METS} = {} & 14.7873 + (\text{age} * 0.1159) - (\text{age-squared} * 0.0017) \\ & - (\text{BMI} * 0.1534) - (\text{WC} * 0.0085) - (\text{RHR} * 0.0364) \\ & + (\text{active} * 0.5987) - (\text{smoking} * 0.2994)\end{aligned}$$

Men

$$\begin{aligned}\text{METS} = {} & 21.2870 + (\text{age} * 0.1654) - (\text{age-squared} * 0.0023) \\ & - (\text{BMI} * 0.2318) - (\text{WC} * 0.0337) - (\text{RHR} * 0.0390) \\ & + (\text{active} * 0.6351) - (\text{smoking} * 0.4263)\end{aligned}$$

METS	metabolic equivalent of task.
Age	expressed in years
BMI	body mass index (measured; kg/m^2)
WC	waist circumference (measured; cm)
RHR	resting heart rate (measured via radial palpation; beats per minute)
Active	coded as "1" if the participant self-reported at least 2000 MVPA MET-min-month (equivalent to current MVPA guidelines), otherwise coded as "0"; details on this self-reported MVPA assessment has been described elsewhere [29]
Smoking	coded as "1" if self-reported being a current smoker, otherwise coded as "0".

2.5. Statistical analyses

Analyses were performed using Stata (version 12.0) and accounted for the complex survey design employed in the NHANES. To examine the associations between sedentary behavior and cardiorespiratory fitness with cognitive function (outcome variable), a weighted multivariable linear regression model was employed; two models were computed, one evaluating the independent and the other evaluating the combined associations of sedentary behavior and cardiorespiratory fitness on cognitive function. In

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